I. INTRODUCTION

Neutron collars* (UNCLs)[1] are being used for routine inspection activities by both the International Atomic Energy Agency (IAEA) and the Commission of the European Communities (CEC) Safeguards Directorate, Luxembourg (EURATOM). This activity has led to increased requirements for an absolute calibration for each of the collars and a procedure to carry over the calibration to different nuclear facilities. Achieving this kind of standardization is complex because the fuel assemblies include many different enrichments, pin configurations, fuel masses, and burnable poison loadings.

To obtain an absolute calibration of the UNCL requires measuring a group of standard boiling water reactor (BWR) and pressurized water reactor (PWR) fuel assemblies that cover a wide range of fuel enrichments and dimensions. During past calibration work, data of this type were obtained for PWR fuel at Franco-Belge de Fabrication de Combustibles (FBFC),[2] for BWR fuel at ASEA-Atom[3] in Sweden in 1982, and for both types of fuel at Exxon Nuclear at Richland, Washington, during 1984-1985.[4] However, calibration data for fuel assemblies containing burnable poison rods were not obtained during this early work.

More recently, the use of burnable poison rods in both BWR and PWR fuel assemblies has greatly increased. This has made it necessary to recalibrate the collar for the case of poison rod assemblies. To gain independence from the operator's declaration for the number of poison rods, cadmium (Cd) liners have been included with the collar, and a combination of measurements with and without the Cd liners can be used to verify the amount of burnable poison in the assemblies.

The Cd liners remove the low energy (thermal) neutrons from the interrogation spectrum and thus reduce the poison rod perturbation to the assay by about a factor of 10. If the measurements are performed using **only** the Cd liner mode, the measurement **variations** caused by the poison rods can be neglected in some cases. However, long measurement times (20-40 min) are required in the Cd mode, so it is more practical to measure most of the assemblies in the no-Cd mode. A ratio of measurements with and without the Cd liners (Cd ratio) can be used to verify the operator's burnable poison declaration. Both calibrations with and without Cd liners will be given in this report.

During 1989, a new version of the collar the (UNCL-II) was introduced to reduce measurement times and to take advantage of the high reliability and stability that is possible with the new AMPTEK electronics.[5] This unit has a fixed body size, so separate detector heads are used for PWR and BWR fuel assemblies. A description of the UNCL-II will be given in this report.

This report summarizes calibration information needed for the PWR and BWR calibration work. After the absolute calibration has been performed for a particular collar, a common reference checkpoint is needed to cross-calibrate additional collars for both fuel types. We performed such a cross-calibration using the Los Alamos National Laboratory prototype fuel assemblies.

The new fuel assembly designs have a wide variation in poison rod loadings and variable enrichments. Results are presented in this report to better quantify the corrections for these variations.

Table I lists collars that are included in the present cross-reference and calibration.

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*IAEA designation is UNCL (Uranium Neutron Collar—Light Water Reactor Fuel). EURATOM designation is NCC (Neutron Coincidence Collar).

Table I. Neutron Collar Listing

Collar	Fabricator's Source No.	Mod	Fabricator (AMPTEK Upgrade)	Location
LANL-3	N/A	II	LANL	LANL
LANL-4	N/A	II	LANL	LANL
IAEA-BWR/1	88-049-01	II	JOMAR	IAEA/Japan
IAEA-BWR/2	88-049-02	II	JOMAR	IAEA/Japan
IAEA-PWR/3	88-049-03	II	JOMAR	IAEA/Japan
IAEA-PWR/4	88-049-04	II	JOMAR	IAEA/Japan
LANL-1	N/A	I	LANL	LANL
IAEA-4887/1	--	I	NNC	IAEA/Vienna
IAEA-4887/3	88-0739C	I	NNC	IAEA/Korea
IAEA-4887/4	88-049-10	I	JOMAR	IAEA/Vienna
IAEA-4887/5	--	I	JOMAR	IAEA/Vienna
IAEA-4887/7	--	I	NNC	IAEA/Vienna
IAEA-4887/8	--	I	JOMAR	IAEA/Vienna
IAEA-4887/spare	--	I	NNC	IAEA/Vienna
IAEA-88-049-08	88-049-08	I	JOMAR	IAEA/Vienna
IAEA-88-049-09	88-049-09	I	JOMAR	IAEA/Vienna
EUR (BWR/PWR-3)	--	I	JOMAR	EUR/Lux.
EUR (BWR/PWR-5)	--	I	JOMAR	EUR/Lux.
EUR (JOMAR 1988)	Pur. 1988	I	JOMAR	EUR/Lux.

II. NEUTRON SOURCE-SAMPLE COUPLING

The response from the UNCL is directly proportional to the AmLi neutron source intensity and the source-sample coupling. However, the response varies as the square of the detector efficiency. Thus it is important to keep track of the source and the sample spacing in the UNCL. The normal procedure is to keep an assigned source with a specific UNCL. However, in some field applications, it is necessary to substitute a different source because of transportation and licensing problems. In case of substitution, the AmLi source yields and ratios given in Table II can be used to correct the response. The response varies linearly with the source strength.

Table II. AmLi Source Yield Comparison

Source No.	Absolute Yield[a] (n/s)	Yield Relative to MRC-95	Location
MRC-67	2.20×10^4	0.554	Los Alamos
MRC-68	1.14×10^5	2.872	Los Alamos
MRC-75	6.98×10^3	0.1760	IAEA
MRC-77	6.45×10^3	0.1633	IAEA
MRC-79	4.38×10^4	1.107	IAEA
MRC-80	4.21×10^4	1.062	IAEA
MRC-81	4.11×10^4	1.037	IAEA
MRC-82	3.79×10^4	0.956	IAEA
MRC-91	3.83×10^4	0.995	IAEA
MRC-92	3.94×10^4	0.996	IAEA
MRC-93	4.13×10^4	1.042	IAEA
MRC-94	4.01×10^4	1.013	Los Alamos
MRC-95	3.96×10^4	1.000	Los Alamos
MRC-96	4.00×10^4	1.009	Los Alamos
MRC-99	7.53×10^4	1.899	Los Alamos
MRC-100	7.31×10^4	1.845	Los Alamos
MRC-104	4.53×10^4	1.144	IAEA
MRC-105	4.38×10^4	1.106	IAEA
MRC-110	4.15×10^4	1.048	IAEA
MRC-111	4.48×10^4	1.132	IAEA
MRC-112	4.56×10^4	1.150	IAEA
MRC-113	4.80×10^4	1.211	Los Alamos/IAEA
MRC-114	4.62×10^4	1.164	Los Alamos/IAEA
MRC-115	5.10×10^4	1.287	Los Alamos
MRC-116	5.17×10^4	1.305	Los Alamos
MRC-117	4.83×10^4	1.220	Los Alamos
MRC-118	4.83×10^4	1.220	Los Alamos
MRC-121	6.46×10^4	1.628	EURATOM
C-119	4.52×10^4	1.142	EURATOM
C-171	4.78×10^4	1.207	IAEA
C-172	4.72×10^4	1.193	IAEA
C-173	4.79×10^4	1.190	IAEA/Japan
C-176	4.96×10^4	1.255	EURATOM
C-180	5.03×10^4	1.270	EURATOM
C-181	4.80×10^4	1.211	EURATOM
C-182	4.73×10^4	1.193	EURATOM
C-183	4.66×10^4	1.176	EURATOM
C-186	4.00×10^4	1.009	IAEA
C-188	4.21×10^4	1.063	IAEA
C-268	3.97×10^4	1.003	IAEA
C-270	5.48×10^4	1.382	EURATOM
C-271	4.64×10^4	1.169	EURATOM
C-272	4.00×10^4	1.009	IAEA
C-282	5.84×10^4	1.474	EURATOM
C-283	5.71×10^4	1.439	EURATOM
C-287	5.70×10^4	1.440	EURATOM
C-297	4.36×10^4	1.102	EURATOM
C-298	4.42×10^4	1.108	EURATOM
C-299	4.52×10^4	1.138	EURATOM
C-300	4.40×10^4	1.109	EURATOM
C-470	4.48×10^4	1.132	IAEA
C-471	4.57×10^4	1.153	IAEA
C-472	4.50×10^4	1.136	IAEA
C-473	4.42×10^4	1.116	IAEA
C-474	1.01×10^5	2.554	IAEA
C-475	1.04×10^5	2.627	IAEA
C-476	1.02×10^5	2.580	IAEA
C-477	1.03×10^5	2.600	IAEA
C-539	9.90×10^4	2.499	IAEA
C-540	9.94×10^4	2.511	IAEA
C-541	1.03×10^5	2.610	IAEA
C-542	9.77×10^4	2.468	IAEA

[a] The absolute yield is based on the ratio of the totals rate to ^{252}Cf (CR-5) in the center of a two-ring AWCC. The efficiency for the ratio of AmLi/Cf was 1.055 based on MCNP calculations. The yields correspond to January 1, 1989.

The previous AmLi sources used with the UNCL units had a yield of ~5 x 10^4 n/s; however, the newer UNCLs have source strengths of ~9 x 10^4 n/s to better override the neutron background from the fuel assembly. For the Cd-mode interrogation, the induced signal rate is an order of magnitude less than for the no-Cd mode; therefore, the stronger source helps to reduce measurement times by increasing the signal/background ratio.

The source-sample coupling is fixed by positioning the fuel assembly face 1 cm away from the polyethylene (CH_2) side holding the AmLi source. The AmLi source has a fixed position in the UNCL.

III. DETECTORS

Detector and electronic counting efficiency depend on three components: the ^{3}He tube detectors, the sample-detector solid angle, and the electronics. The first of these is essentially constant for a given system, whereas the solid angle and the electronics can change from one setup to the next. If the same electronics are used from one application to the next and the high-voltage setting is not altered, experience shows we can expect to obtain better than 1% stability in the totals rate.

One of the primary sources of error in using the UNCL in the past has been improper field assembly of the four sides. When these sides are misaligned, the detector's efficiency changes. Also, in some nuclear fuel facilities, there has not been adequate clearance to open and close the hinged door of the UNCL.

To help eliminate these problems and to decrease the required measurement times, the UNCL-II was introduced in July 1989.

UNCL-II Design

The UNCL-II has the following characteristics that are different from the UNCL:

- Separate detectors for BWR and PWR assemblies with a single U-shaped AMPTEK[5] junction box,
- A lift-out door containing the AmLi neutron source, and
- Higher detector efficiency than the original UNCL.

The new detector schematic design is shown in Fig. 1 for PWR together with that of the original UNCL. Figure 2 is a photograph of the UNCL-II with the AMPTEK box lid removed. Figure 3 is a diagram of the original UNCL (top) and the new UNCL-II (bottom) corresponding to BWR-size fuel. Figure 4 shows the experimental setup with the collar positioned on a BWR fuel assembly. Table III gives the specifications for the old and new systems.

The detector tubes are set to operate with HV = 1680 V and a gate of 64 μs, which is the same as for the HLNC-II.

The deadtime of the UNCL is negligible, so the deadtime coefficient is set equal to zero ($\delta = 0$) for **both** calibration and assay.

IV. CALIBRATION METHODS

During the past several years, neutron coincidence collars have been calibrated from reference fuel assemblies in Belgium (PWR),[2] Sweden (BWR),[3] and at the Exxon Nuclear[4] facility (PWR and BWR). Various ^{235}U enrichments were used to establish the shape of the calibration